Journal of Forensic and Legal Medicine 19 (2012) 144–151

Contents lists available at SciVerse ScienceDirect

Journal of Forensic and Legal Medicine

journal homepage: www.elsevier.com/locate/jflm

Original communication

Focal traumatic brain stem injury is a rare type of head injury resulting from assault: A forensic neuropathological study

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ARTICLE INFO

Article history:
Received 10 June 2011
Received in revised form
18 July 2011
Accepted 18 December 2011
Available online 27 January 2012

Keywords:
Head injury
Focal traumatic brainstem injury
Diffuse axonal injury
Mechanism of head injury

ABSTRACT

Introduction: Brainstem haemorrhage is common in cases of head injury when it is associated with space-occupying lesion and increases in the intracranial pressure (duret haemorrhage), in cases of diffuse axonal injury (in dorso-lateral quadrant) and diffuses vascular injury (in the periventricular tissue). However focal traumatic brainstem injury is rare.
Material and method: We identified 12 cases of focal traumatic brainstem injury from review of 319 case of head injury. The head trauma had been caused by different mechanisms of complex fall from height and assault. 10/12 are associated with skull fracture, 11/12 with contre coup contusions in the frontal and temporal lobes, 5/12 direct contusions to cerebellum, 5/12 haemorrhage in corpus callosum and 2/11 have gliding contusions. None of the cases had pathological evidence of increase in the intracranial pressure. The bleeding in the pons was at the edge in 2/12 and cross the section in 10/12. The majority of patients were unconscious immediately after the incident (10/12) and 9/12 died within one day.
Conclusion: Focal traumatic brainstem injury occurs most likely due to direct impact at the back of the head or stretching forces affecting the brainstem in cases of complex fall from height and after assault, particularly those associated with kicks. It is a serious and commonly fatal brain damage, which needed to be differentiated from other causes of brainstem haemorrhages.

1. Introduction

Damage and haemorrhage to brainstem structures are frequently seen in cases of head injury; the majority of these are secondary haemorrhage in the brainstem resulting from increased intracranial pressure and brain herniation. This is commonly seen as a secondary event in cases such as extra or subdural haemorrhage or intracerebral bleeding following head injury. In such cases the haemorrhage in the brainstem is usually in the midline but it could also involve other parts or the whole cross-section of the brainstem.[1–3]

The second type of brainstem haemorrhage encountered in cases of head injury is a primary damage caused directly by trauma due to physical effect of traumatic forces damaging cells, axons and blood vessels, and this primary type can itself be divided into 2 distinct types.

The first is when the brainstem damage is seen as part of diffuse process such as diffuse axonal injury (DAI). In such cases small haemorrhages in the brainstem are seen together with supratentorial lesions such as haemorrhage in the corpus callosum and widespread damaged axons in the supra and infratentorial areas like white matter of cerebral hemisphere, corpus callosum, internal capsule, middle cerebellar peduncles, basis pontis and midbrain. The brainstem haemorrhages in DAI are typically seen as small foci in the dorso-lateral quadrants of the brainstem and in the superior cerebellar peduncles and can also involve the periventricular tissue (around the fourth ventricle). The small haemorrhages around fourth ventricle are also seen in another type of severe head injury which is called diffuse vascular injury (DVI) in which multiple pinpoint haemorrhages in the cerebral white matter are seen.[3–7]

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doi:10.1016/j.jflm.2011.12.015

The second type of primary brainstem haemorrhage due to head injury is the focal brainstem injury due to trauma which is characterised by localised damage to the brainstem structures without significant supratentorial brain damage or increased intracranial pressure or brain herniation. Some of these cases are represented by what is called ponto-medullary rent which is characterised by laceration and tearing at the junction of the pons and medulla oblongata resulting in partial or complete separation of these structures.[8,9] However, there are other lesions in brainstem injury which are not associated with tear and involve mainly the midbrain and pons but not the medulla, therefore can be described as focal traumatic brainstem injury "FTBSI". These could occur as a focal contusion and laceration to brainstem which is often associated with base of skull fracture. They may result from direct impact to the brainstem or from extreme hyper-extension and hyper-flexion and twisting of brainstem resulting from violent forces.[3,10–13]

Previous neuropathological studies prior to CT scan assessment suggest such FTBSI lesions are very rare and probably never occur without concurrent diffuse brain damage.[4,14,15] However, since the introduction of CT and more significantly MRI scans the focal primary brainstem injury has been recognised more frequently. Literature based on CT and MRI studies indicated that a brainstem lesion is common in some cases of head injury and is usually fatal particularly if it involves the brainstem bilaterally and it is associated with a supratentorial lesion. However, isolated traumatic brainstem lesions may occur but are extremely rare.[10,12,16,17]

Previously neuropathological studies on brainstem injuries have concentrated on the specific lesions of ponto-medullary rent,[8,9] with only a few neuropathological studies investigating the criteria of primary focal brainstem injury. Furthermore, most publications have been based on a single case report and on certain types of events such as road traffic accidents.[18–20]

In this study, we aim to establish the neuropathological criteria of the focal traumatic brainstem injury (FTBSI) and correlate them with clinical history and the mechanism of injury. Most of the patients in our study have been injured secondary to assault or accidental fall.

2. Methods

2.1. Reviewed cases

We reviewed the neuropathological criteria of 319 consecutive head injury cases resulted from assault referred to our institution over a period of four years.

2.2. Autopsy examination

All the reviewed cases had undergone comprehensive forensic examination of the deceased, including detailed external and internal examination with detailed examination to head and neck regions, the site and extent of the injuries and bruises and site, distribution and extent of skull fractures were carefully recorded. The size and site of extra and subdural haematoma were documented. The brain was then removed in total and placed, together with dura and haematoma (if present), and submitted for neuropathological examination by one of the authors (*SAlS*). In each case there was detailed clinical history and circumstances of death.

2.3. Neuropathological examination

After fixation in 10% formalin, for minimum of three weeks, the brain was examined externally with full assessment of site and degree of contusions and laceration and degree and distribution of subarachnoid haemorrhage. The site and size (or weight) of extra or subdural haematoma were recorded. The brain was then cut coronally to 0.7 cm thick slices; each of them was assessed regarding pathological features. Special attention was paid to presence of contusion, intracerebral bleeding, gliding contusions, haemorrhage in corpus callosum, basal ganglia and hippocampi, intraventricular bleeding and presence of other pathologies like ischaemia and infarction.

Eight standard large blocks to investigate the axonal injury from (1) frontal lobe to include parasagittal white matter; (2) parietal lobe to include central semi-ovale, (3) anterior corpus callosum (4) splenium; (5) basal ganglia and thalamus to include posterior limb of the internal capsule, (6) hippocampus; (7) cerebellum to include middle cerebellar peduncle and (8) pons to include basis pontis and superior cerebellar peduncle, were taken. This is in addition to sampling contusions, site of haemorrhage and area of infarction if present. Samples from sub or extradural haemorrhage with dura were submitted for histology. All the blocks were stained with H&E and Perl's (if haemorrhage present) and immunohistochemical staining for β amyloid precursor protein (βAPP): 7 μm paraffin sections on slides coated with 3 aminopropyltriethoxysilane were used. Sections were dewaxed in xylene, rehydrated in 99% industrial methylated spirit and endogenous peroxide activity was blocked by incubation for 3 min at room temperature (RT) in 2000 ml methanol containing 5 ml H_2O_2. Sections were washed well in running tap water and placed in TRIS buffered saline (TBS) pH 7.8 for a few minutes and subsequently microwaved in a plastic container containing 400 ml nitrate buffer pH 6.00 "high" (800 W) for 2 periods of 6 min in a Panasonic microwave. The excess TBS surrounding the sections was wiped and sections were ringed with vector pen. It was followed by incubation in 10% dakocytomation normal rabbit serum for 30 min at RT then the serum was drained off the slides. Sections incubated in monoclonal anti-βAPP IgG as primary antibody (Chemicon, Chandlers Ford, UK, Clone EZCII) at a dilution of 1:10,000 at 4 °C. After two rinses in TBS for 5 min each change, the sections were incubated in 1:200 dakocytomation rabbit anti-mouse IgG for 45 min at RT. Sections were washed in two changes for TBS for 5 min each change. For CD68, the primary monoclonal antibody (Dako, Ely, UK, Clone PGM1) was applied overnight at 4 °C in 1:1000 dilution. After rinsing in TBS sections were incubated with biotinglated rabbit anti-mouse IgG (1:200, Dako) in TBS for 45 min at RT. After extensive rinsing, sections were incubated in preformed avidin–biotin horseradish peroxidise (ABC-HRP complex, Dako) complex for original amplification. The reaction product was visualised using a solution of 10 mg 3.3 diaminobenzidine tetrahydrochloride (DAB, Sigma, Gillingham UK) as chromagen dissolved in 20 ml TBS. The solution was filtrated and 10 ml of 30% H_2O_2 was added to it. The sections were incubated at RT for 10 min standard control experiments were performed by omission of the primary antibody and resulted in no detectable cellular immuno-labelling.

2.4. Criteria of selection

We have selected cases of focal traumatic brainstem haemorrhage excluding:

1) Haemorrhage secondary to increase in the intracranial pressure;
2) Small (pinpoint) brainstem haemorrhage in the dorso-lateral quadrants, superior cerebellum if it is part of DAI and DVI (please see introduction);
3) Pontine haemorrhage due cerebrovascular accident (stroke)
4) Bleeding in the pons resulting from fat embolism
5) Bleeding in the brainstem if due to altered blood coagulation and disseminated intravascular coagulopathy commonly seen in terminally ill patients and usually seen with haemorrhages in other parts of the brain.

We included cases of brainstem haemorrhage where the haemorrhage is seen extensive and out of proportion expected (not typical) in DAI or DVI.

3. Results

3.1. Incidence

We have found 12 cases which fulfil all of our above criteria of focal traumatic brainstem injury from the review of 319 cases head injury; an incidence of 3.7% (Table 1).

3.2. Circumstances of death

7/12 cases of focal brainstem haemorrhage had resulted from complex fall down stairs and from height or from accelerated backwards fall (after a punch) followed by kicks. In another 4/12 cases the deceased were beaten with kicks and stamping. In 1/12 the head injury is caused by severe impact on the top or front of the head.

3.3. Survival

In 10/12 cases the victims were unconscious after head injury or found dead; six died within few hours, 3/11 died after one day and one after two days. One case had no available history.

3.4. Skull fractures

Skull fractures were present in 10/12 cases; in 8 the skull fractures were in the occipital bone and posterior fossa involving foramen magnum and in 2 the fractures were at the base of the skull.

3.5. Brain macroscopic examination

Subdural haematoma of less then 30 ml in volume were presented in 4 cases. 8/12 cases show subarachnoid haemorrhage which is patchy, mainly over the dorsal surface of the brain, sometimes in association with the contusions. In 11/12 cases there were countercoup contusions in the inferior surfaces of the frontal and/or temporal lobes. Direct impact (coup) contusions were seen in posterior cerebellum in 5 cases and dorsal surface of the cerebrum in 3 cases. Two cases show parasagittal, linear haemorrhage consistent with gliding contusion. A small haemorrhage in corpus callosum was seen in 5/12 cases.

The most common site of the bleeding was seen across the sections of the brainstem. In 10/12 patients the haemorrhage in the brainstem is widespread and across the section involving most structures, three mainly in the basis pontis and two cases only at the edge of the brainstem.

3.6. Microscopic examination

Established ischaemia in the cerebral cortex and hippocampus were seen in 5/12 cases. In these cases, shrunken neurons with dense nuclei and hyper-eosinophilic cytoplasm were present associated with over-expression of βAPP in the neuronal cytoplasm. In these four cases and additional four (total 8), the βAPP also showed axonal damage in the white matter tracts in pattern consistent with ischaemia. The βAPP was seen as ill-defined area with heavy granular background.

The βAPP showed a pattern consistent with traumatic axonal injury in 3 cases. In these, the βAPP deposits were seen with well-defined globules and filaments with no granular background and running along white matter bundles.

In one case (case 1), the βAPP deposits which are consistent with traumatic pattern were only localised to the corpus callosum and internal capsule.[21,22] In two other cases (cases 3 and 11), the traumatic axonal damage was seen in supratentorial parts (white matter of frontal and parietal, internal capsule and corpus callosum) and infratentorial part (pons and cerebellar white matter). In these two cases, the brainstem haemorrhage was seen localised to the edge of the brainstem and not involving the periventricular tissue or superior cerebellar peduncle and associated with fractures in the posterior fossa including the foramen magnum, therefore more consistent with localised contusions and lacerations than small haemorrhage associated with DAI or DVI.

In case 9 (Figs. 1–4) the appearances of the haemorrhage in the brainstem raises the possibility of secondary bleeding due to increase in the intracranial pressure. But the features that the subdural haematoma was small (20 ml in volume), the brain was not swollen and there was no evidence of brain shifting or herniation, excludes this possibility. The patient was immediately unconscious after the assault and died in less than 1 h. This is an important fact to supports the view that the bleeding in the brainstem is likely to be due to primary injury rather than secondary to increase in the intracranial pressure.

4. Discussion

There are articles in neuropathological literature describing brainstem injury causing ponto-medullary rent; most are caused by road traffic accidents but there is noticeable lack of neuropathological articles describing other types of focal injury to the brainstem, particularly in cases of assaults. In 1973, Mitchell and Adams question the existence of isolated traumatic brainstem injury.[13] They have reviewed 100 fatal head injuries and identified seven cases where there was evidence of damage elsewhere making the brainstem injury part of what is probably DAI.[13] The view that brainstem injury is a component of more generalised DA was stressed upon more by Adams et al. (1977) who found brainstem lesion in 19/151 fatal head injuries, all associated with bleeding in corpus callosum and showing evidence of DAI.[14] More recently, Shukla et al reported brainstem injury in 7/47 head injury patients but no clear pathological examination of the brain was provided.[18]

However, focal TBSI is more described in article bases on CT and MRI appearances.[10,12,13] Isolated traumatic brainstem lesion was found in 5/21 by Hashimoto et al. and 2/100 patients of severe head injury by Firsching et al. These patients had poor prognosis and died from their injury.

In this article we present a comprehensive study in which we identified the primary and focal TBSI in victims subjected to assaults and we investigated the mechanism and characterised neuropathological features. We found the incidence of focal TBSI is 3.3% which is comparable with those evidence based on MRI studies by Firsching et al.[13]

Most of our cases were investigated under medico-legal process and involve cases of assaults or suspicious death but none was from road traffic accident. Therefore, further studies including head injury of road traffic accidents and accident of fall from significant height would increase our knowledge about this type of head injury.

The damage in the brainstem in our 12 cases was different from those described under ponto-medullary rent. In none of our cases was there tear or damage to ponto-medullary junction. The haemorrhages and damage was confined to part or cross-section of midbrain and pons. For this reason, we differentiate them from ponto-medullary rent and labelled them as focal TBSI.

The focal TBSI injury in our study occurs most commonly after heavy impact at the back of the head, like those resulting from accelerated fall or complex (more than one hit) fall down the stairs.

Table 1
Clinical and pathological description of focal traumatic brainstem injury. M: male, F: female, WM: white matter, CC: corpus callosum, SDH: subdural haematoma, SAH: subarachnoid haemorrhage, TAI: traumatic axonal injury, IAI: ischaemic axonal injury, DAI: diffuse axonal injury.

No	Age/ sex	Incident	Skull fracture	Scalp bruises	Coup contusion	Countercoup contusion	Other lesion	Axonal injury by βAPP	Brainstem haemorrhage	Clinical presentation
Case 1	20 M	Thrown from the top of a flight of stairs	-Base of skull extending to foramen magnum -Left temporal bone	-Right and left temporalis -Facial	Right and left cerebellum	Temporo-occipital	Brain swelling	-Muilti focal TAI -Focal IAI (in brainstem and cerebellum	-Periventricular -Midline -SCP -Left edge	Unconscious then died 2 days later
Case 2	80 M	Hit at the back of head, falling and hitting the ground on the top of the head	Ring fracture around foramen magnum	Back and top of head and face	None	None	-SAH -Small haemorrhage in CC	Early axonal injury	Cross-section of pons	Unconscious, survived 45 min
Case 3	44 M	Found dead, possibly stamped on, head and neck and kicking	Midline of occipital lobe extending to foramen magnum	Right and left parietal and occipital regions	Right temporal and right frontal	None	Intraventricular bleeding	DAI	left edge of the brainstem	Found dead
Case 4	36 M	Punched to the face, fell backward striking hard object and kicks	-Mandibular fracture -Fracture of occipital bone	On top of head and in occipital region	None	Frontal and temporal lobes	-Brain swelling -SAH -Small haems in wm and internal capsule -Ischaemia	IAI	-Periventricular -Basis pontis -SCP	Unconscious, survived one day
Case 5	51 M	Falling down flight of stairs	Occipital fracture	Occipital region	Left cerebellum and vermis haemorrhage	Frontal temporal lobe	-Thin SDH -SAH -Ischaemia	IAI and focal TAI	Cross-section of pons extends to thalamus	Unconscious, survived one day
Case 6	63 M	Accelerated fall backwards striking head on the ground	Base of skull fracture	Occipital region	-Dorsal surface of frontal parietal occipital -Cere-bellum	Frontal temporal	-SAH -Gliding contusions -Intraventicular bleeding -thalami	IAI	Periventricular and basis pontis	Not available
Case 7	32 M	Beaten with bricks and kicks and stamping	No	-Right and left at back of scalp; -Neck	None	Inferior frontal	-SAH -Gliding contusion -CC	IAI and focal TAI	Periventricular and basis pontis	Unconscious after assault, found dead later in the same position 4 h later
Case 8	64 M	Found lying at bottom of stairs	-Fracture in occipital and temporal bones	Occiput and right side of scalp	Middle frontal gyrus	Inferior frontal and temporal	-Small SDH -SAH	No histology	Periventricular basis pontis	Unconscious
Case 9	43 M	Punched, fell backward hitting head on the ground. Possible kicks to the head	-Occipital and posterior fossa extend to foramen magnum	Occipital region	Right cerebellum	Inferior frontal	-20mSDH -SAH -Small bleedings in WM and CC	Early AI possibly ischaemia	-Basis pontis -SCP	Unconscious, died at the scene (less than 1 h)
Case 10	55 F	Found unconscious, possible impact from or against a blunt object	None	Forehead	No	Frontal	-SAH -Ischaemia	IAI	-Basis pontis -Pons and midbrain	Unconscious, died few hours later
Case 11	30 M	Found unconscious in the street after being assaulted	Left temporal extending to the base of the skull and sella tursica	Right and left parietal areas	Superior and lateral surface of the right frontal lobe	Inferior and lateral surface of the right temporal lobe	30 ml SDH	DAI	Localised to the left side of the pons	Survived 15 h
Case 12	46 M	Fell down stairs	Fracture of occipital bone	Occipital region	Inferior surface of cerebellum	Inferior frontal and temporal	-Small haemorrhage in CC -SAH	IAI	Periventricular and superior colliculi	Found dead

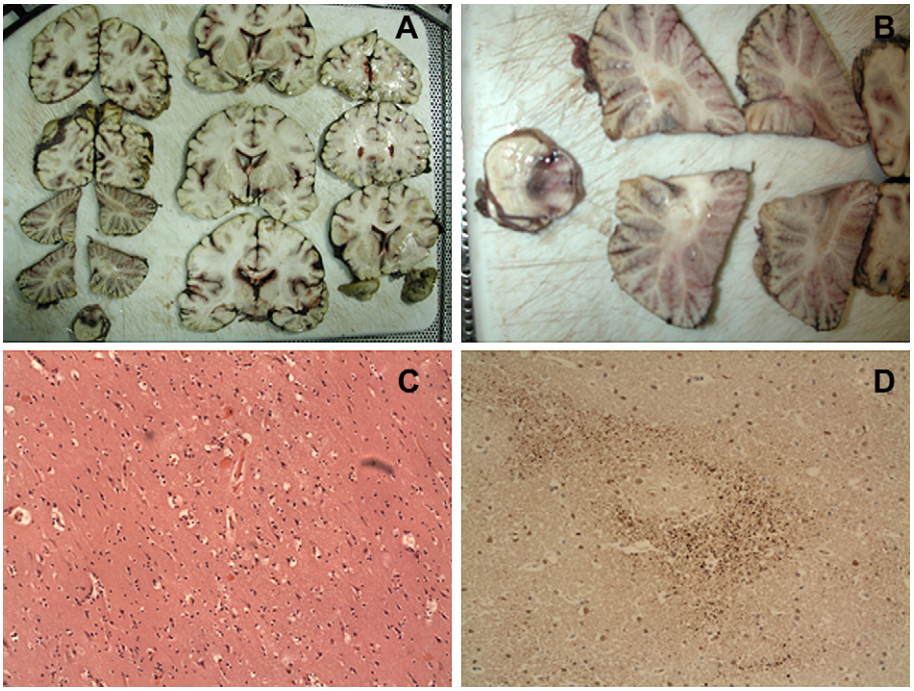

Fig. 1. Case 6 (see Table 1) (A) Coronal sections, contusions in the inferior surfaces of the right frontal and right temporal lobes (B) Multipe haemorrhages in the tectum of the pons (C) Ischaemic changes in the neurones of the parietal cortex (D) Deposition of βAPP in the white matter of parietal lobe as ill-defined areas with granular patterns consistent with recent ischaemic disruption of axons.

It also appears that kicks at the back of the head, in addition to the local heavy impact, would cause violent movement of the head in unconscious or semi-unconscious patients. Another rare mechanism is heavy impact on the top of the head pushing the brain and the brainstem down towards the spinal cord and associated with a ring fracture around the foramen magnum. In fact, most of our cases (10/12) are associated with skull fracture. The presence of 8/12 cases with fracture in the occipital bone and posterior fossa support the importance of heavy impact at the back of the head as common mechanism for the brainstem haemorrhage.

This fact is further consolidated by a high proportion of cases with countercoup contusions (11/12) in the frontal and temporal

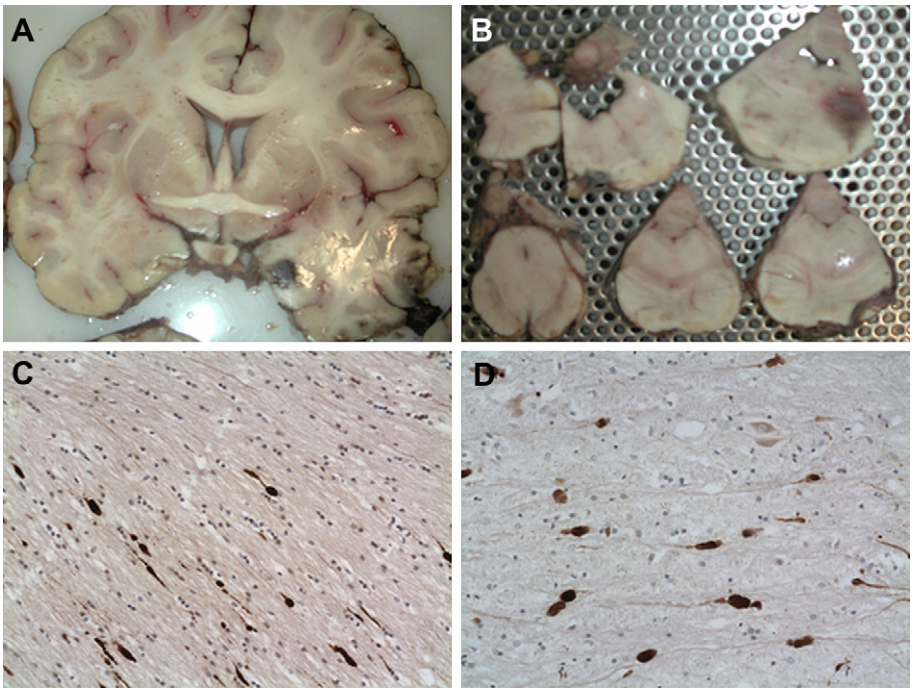

Fig. 2. Case 11 (A) Coronal sections at the level of anterior lentiform nuclei. There are contusions in the lateral and inferior surfaces of the temporal lobe and the middle frontal gyrus. No evidence of brain shifting or herniation (B) Haemorrhage at the left edge of the pons (C & D) βAPP staining showing well-defined axonal swellings in the corpus callosum and white matter of frontal lobe consistent with traumatic injury to the axons.

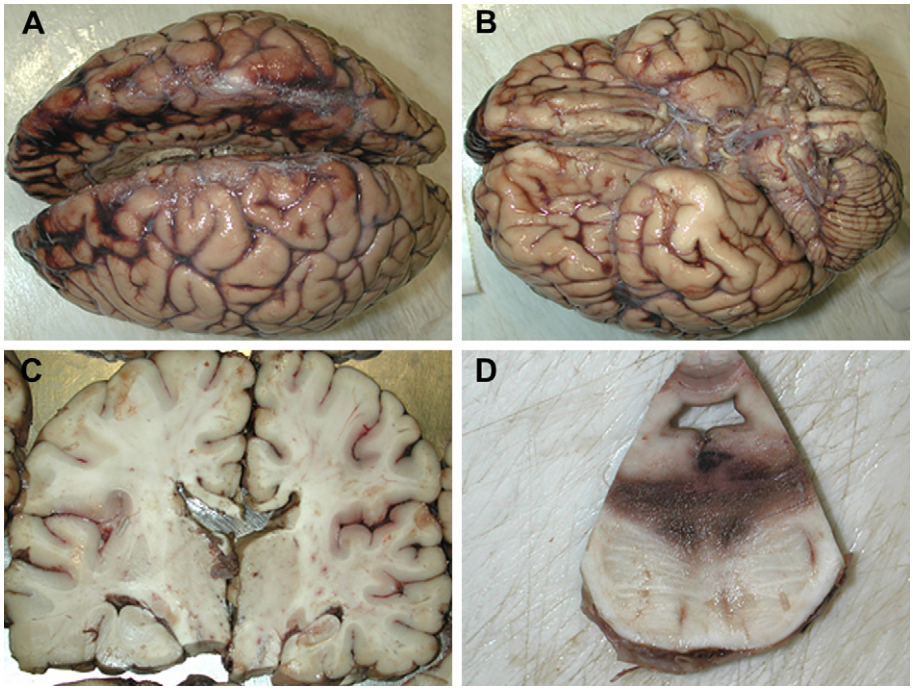

Fig. 3. Case 7 (see Table 1) (A) Dorsal aspect of cerebral hemispheres. There are small patches of subarachnoid haemorrhages in the medial and parasagittal areas of the cerebral hemispheres (B) Ventral surface of the brain. Showing no evidence of uncal or tonsilar herniation and no brain shifting. (C) Symmetrical cerebral hemispheres with no uncal herniation (D) Pons showing diffuse haemorrhages involving the tectum in absence of increased intracranial pressure.

lobes and many cases (5/12) with contusions in the posterior lobes of the cerebellum. The impact at the back of the head may cause shear strain on the brainstem around the notch of the tentorium. Considering the anatomical structure of the tentorium and the perforating artery, the brainstem could easily and may be selectively injured. It is also possible that the direct impact which had caused skull fracture in the posterior compartment may probably cause direct injury to the brainstem by the edge of the tentorium.

None of our cases showed a fracture to the cervical vertebra or injury to the spinal column. In case 10 the main severe impact was judged to be on the forehead with direct coup contusions in the anterior part of the frontal lobes. However, the brainstem shows

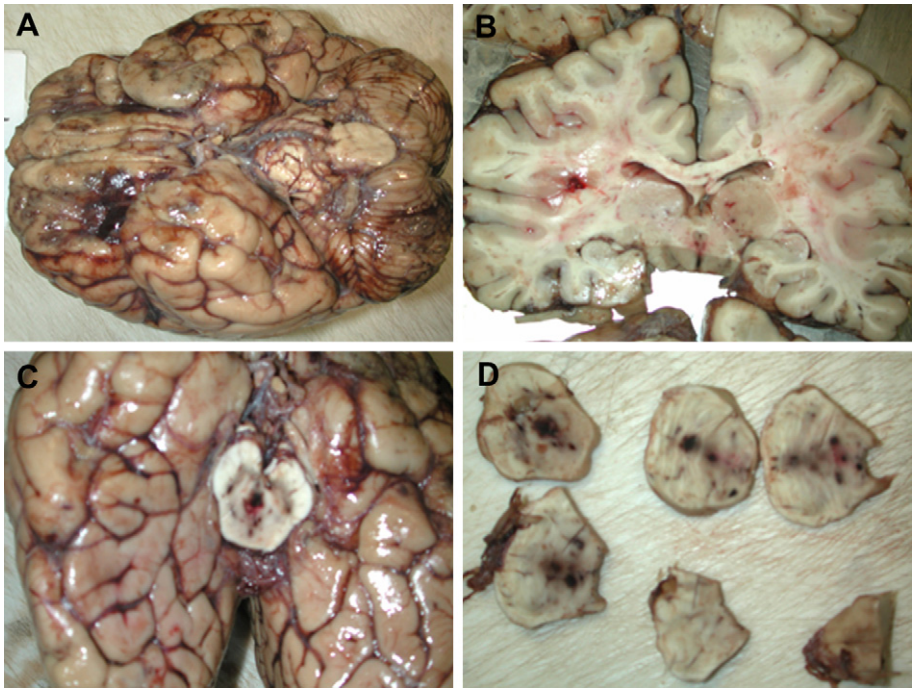

Fig. 4. Case 9 . The brain is not swollen; weight 1401, the SDH was 20 ml, no brain herniation, patient died at the scene (less than 1 h); all of these exclude secondary Dure't brainstem haemorrhage. (A) Basal surface of the brain. There are diffuse contusions in the inferior surfaces of the frontal and temporal lobes. No brain shifting or herniation (B) Slice at the level of pulvinar. The hipocampi are symmetrical with no evidence of herniation of unci (C) Brainstem haemorrhage and unci are normal (D) Multiple small haemorrhages in the midbrain and pons in the absence of evidence of increase in intracranial pressure or brain herniation.

multiple haemorrhages. Therefore, it is most likely that haemorrhage in the brainstem in this case was caused by severe hyper-extension and/or hyper-flexion of the head and neck causing more strain on brainstem. A further mechanism described[10] is brainstem injury caused by caudal displacement of the brainstem from force generated by impact on the top of the head. This could be one of the possible mechanisms in case 1.

The head injury was the source of subdural haematoma in 3/12 cases but the haematomas were not large enough volume or enough to have caused significant increase in the intracranial pressure. However, the subdural haematoma is yet another indication of sudden and accelerated movement of the brain.

It is known that haemorrhage of the brainstem involving tegmentum, periaqueductal grey and supra-cerebellar peduncle suggests primary traumatic injury whilst midline haemorrhage is more consistent with secondary haemorrhage following increase in the intracranial pressure. In 6/12 cases the haemorrhage in the brainstem involved all regions of cross-section with involvement of periventricular area and superior cerebellar peduncles. However, in 2 cases[3,11] the damage was more localised to the edge of the brainstem. In both of these cases there were fractures to the base of the skull or occipital bone extending to foramen magnum. Therefore, direct damage and contusions and focal injury to the tentorium is quite possible. However, these two cases show, in addition, histological and immunohistochemical features of diffuse axonal injury with axonal damage being demonstrated in the supra and infratentorial parts of the brain. Therefore, violent rotational acceleration and deceleration of the brain may be another mechanism contributing to the focal TBSI. Accordingly, there are various mechanisms in which focal TBSI can be produced; (a) focal and severe strain around brainstem from twisting or caudal displacement; (b)direct impact including direct push by the edge of tentorium; (c)severe hyper-extension and hyper-flexion; (d) rotational acceleration and deceleration of the brain and brainstem.

It is likely that the damage to the brainstem would have caused disruption of respiratory and cardiac centres and were associated with brain swelling leading to ischaemia in 7/12 cases which is detected by pathological findings i.e. either shrunken acidophilic neurones with βAPP deposition in white matter. Evidence of brain ischaemia was found in 5/12 cases by examining H&E stained sections and 9/12 showed evidence of ischaemic disruption of axons by βAPP where ischaemia would be too early (less then a few hours) to be demonstrated by H&E stain (in one case there was no histology). Such evidence of a high incidence of ischaemia in traumatic brainstem injury is consistent with previous research and supports the suggestion of disruption of cardio-respiratory as a mechanism for brain damage and possibly causing cardiac respiratory disruption. However, ischaemia is common in head injury and could be caused by brain swelling secondary to contusion and laceration and axonal injury.[23,24]

It would appear that the focal brainstem injury is a serious brain damage with fatal outcome. 10/11 patients (one with no history) had immediate loss of consciousness or were found dead and 6/11 died within one day of the injury. However, we have to realise the limitations of this study which in some cases had limited clinical details. Nevertheless, our findings appear to be similar to those published with clinical and radiological review.[25–27] It is possible that the focal TBS injury can cause immediate unconsciousness and death through affecting vital cardio-respiratory centres rather than due to increase in the ICP. Previous MRI studies concluded that the absence of involvement of the brainstem is of prognostic value that even in cases that extensive supratentorial lesion do exist in white matter and corpus callosum, the patient may survive as long as the brainstem is spared. Pilz et al. described two cases of significant brainstem injury with ponto-medullary tear who survived for 8 and 26 days, suggesting brainstem injury is not always rapidly fatal. This is consistent with our findings in case 1 who survived 2 days after the injury.[27]

In Summary: the recognition of focal traumatic brainstem damage in cases of head injury is of particular importance to medico-legal practice and should be differentiated from other types of head injury, particularly brainstem injury secondary to increase in the intracranial pressure caused by DAI and DVI and the ponto-medullary rent. The damage to the brainstem is severe and is not associated with any significant damage in other parts of the brain.

The focal traumatic brainstem injury is often associated with fracture at the base of the skull with extension to the foramen magnum. It could be caused by a number of mechanisms such as direct injury, rotation forces and severe hyper-extension and hyper-flexion of the head and neck with torsion and shearing forces; therefore, both direct and indirect forces are implicated in its pathogenesis.[28]

The characteristics of focal traumatic brainstem injury are:

1) History of head injury commonly with impact at the back of the head.
2) Skull fracture commonly seen in the posterior compartment of the skull
3) No evidence of increased intracranial pressure.
4) The haemorrhage may affect the edge or whole of cross-section of the brainstem.

Conflict of interest

None.

Funding

None.

Ethical approval

None-declared.

Acknowledgement

The authors would like to acknowledge Dr Andrew King for his helpful comments and correction of the article, Mr Lawrence Doey and Phillip Green for their laboratory assistance and Mrs Mary Davitt for her administrative efforts and typing the manuscripts

References

1. Freytag E. Autopsy findings in head injuries from blunt forces: statistical evaluation of 2,367 cases. *Arch Patho* 1963;**75**:402–13.
2. Tomlinson BE. Brainstem lesions after head injury. *J Clin Pathol* 1970;**4**:157–65.
3. Blumbergs P, Reilly P, Vink R. Trauma [Chapter 11]. In: Love S, Lours D, Ellison D, editors. *Greenfield's Neuropathology*. 8th ed. Hadder Arnold; 2008. p. 7330832.
4. Graham DI, Lawrence AE, Adams JH, Doyle D, McLellan DR. Brain damage in fatal non-missile head injury without high intracranial pressure. *J Clincal Pathol* 1988;**41**:34–7.
5. Adams JH, Doyle D, Gennorelli TA, Graham DI, McLellon DR, Ford I. Diffuse axonal injury in head injury: definition, adiagnosis and grading. *Histopathology* 1989;**15**:49–59.
6. Adams JH. Brain damage in fatal non-missile head injury in man. In: Braakman R, editor. *Handbook of clinical neurology*. Amsterdam: Elsevier Sciences; 1990. p. 43–63.
7. Closed brain injury [Chapter 9]. In: Oehmichen M, Auer RN, Konig HG, editors. *Forensic neuropathology and associated neurology*. Springer-Verlag; 2006.
8. Ezzat W, Angl C, Nyssen J. Ponto-medullary rent. A specific type of primary brainstem traumatic injury. *Am J Forensic Med Pathol* 1995;**16**(4): 336–9.
9. Simpson DA, Blumbergs PC, Cooter RD, Kilminster M, McLean AJ, Scott G. Ponto-medullary tears and other brainstem injuries after vehicular accident. *J Trauma* 1989;**29**:1519–25.
10. Hashimoto T, Nakamura N, Richard KE, Frousein R. Primary brainstem lesions caused by closed head injuries. *Neurosurg Rev* December 1993;vol. 16(4).

11. Goscinski I, Kwaitkowski S, Cichonski J, Moskala M. Post-traumatic primary brainstem haematoma. *Acta Neurochir (Wein)* 1995;**134**(1–2):16–20.
12. Firsching R, Woischneck D, Diedrich M, Ruckerk A, Wittig H, Dohring WJ. Early magnetic resonance imaging of brainstem lesions after severe head injury. *Neurosurg* 1998;**89**:707–12.
13. Firsching R, Woischneck D, Klein S, Ludwig K, Dohring W. Brainstem lesions after head injury. *Neurol Res* 2002;**24**:145–6.
14. Adams H, Mitchell DE, Graham DI, Doyle D. Diffuse brain damage of immediate impact type. Its relationship to "primary brainstem damage" in head injury. *Brain* 1977 Sep;**100**(3):489–502.
15. Ropper AH, Miller DC. Acute traumatic midbrain haemorrhage. *Ann Neurol* 1985 Jul;**18**(1):80–6.
16. George B, Thurel C, Pierron D, Ragueneau JL. Frequency of primary brainstem lesion after head injury. A CT scan analysis from 186 cases of severe head trauma. *Acta Neurochri (Wein)* 1981;**59**(1–2):35–43.
17. Meyer CA, Mirvis SE, Wolf AL, Thompson RK, Guttierrez MA. Acute traumatic midbrain haemorrhage: experimental and clinical observations with CT. *The Lancet Saturday* 4 August 1973.
18. Shukla D, Mahaderan A, Sastry KV, Shankar SKL. Pathology of post-traumatic brainstem and hypothalamic injuries. *Clin Neuropathol* 2007 Sep–Oct;**26**(5): 197–209.
19. Zhu BL, Quan L, Ishida K, Taniguchi M, Oritani S, Fujita MQ, et al. Longitudinal brainstem laceration associated with complex basilar skull fractures due to a fall; an autopsy case. *Forensic Sci Int* 2001;**126**:40–2.
20. Saeki N, Yamaura A, Sunami K. Brainstem contusion due to tentorial coup injury: a case report and patho-mechanical analysis for normal cadavers. *B J Neurosurg* 1998;**12**:151–5.
21. Lambri M, Djurovic V, Kibble M, Cairns N, Al-Sarraj S. Specificity and sensitivity of βAPP in head injury. *Clin Neuropathol* 2001;**20**:263–71.
22. Reichard RR, Smith C, Graham DI. The significance of βAPP immunoreactivity in forensic practice. *Neuropathol Appl NEurobiol* 2005;**31**:304–13.
23. Graham D, Adams J, Doyle D. Ischaemic brain damage in fatal non-missile head injury. *J Neurol Sci* 1978;**39**:213–34.
24. Graham D, Ford I, Adams J, Doyle D, Teasdale GM, Lawrence AE, et al. Ischaemic brain damage is still common in fatal non-missile head injury. *J Neurol Neurosurg Psychiatry* 1989;**52**(3):346–50.
25. Wedekind C, Hesselmann V, Lippert-Guner M, Ebel M. Trauma to the ponto-mesencephalic brainstem. A major clue to the prognosis of severe traumatic brain injury. *Br J Neurosurg* 2002;**16**(3):256–60.
26. Mannion RJ, Cross J, Bradley P, Coles JP, Chatfield D, Carpenter A, Pickard JD, Menon DK, Hutchinson PJ. Mechanism-based MRI classification of traumatic brainstem injury and its relation to outcome. *J Neurotrauma* 2007;**24**(1):128–35.
27. Pilz P, Strohecker J, Grobouschek M. Survival after traumatic ponto-medullary tear. *J Neurol Neurosurg Psychiatry* 1982;**45**:422–7.
28. Geddes JF. Axonal damage localised to the cranio-cervical junction. Chapter 8. Primary traumatic brain injury. In: Whitwell Helen, editor. *Forensic neuropathology*. Hodder Arnold; 2005.